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POSSIBILITY OF MEASURING ELECTRON CONCENTRATIONS IN THE UPPER IONOSPHERE AND IN INTERPLANETARY SPACE BY PLASMA WAVE RADIATION *

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POSSIBILITY OF MEASURING ELECTRON CONCENTRATIONS IN THE UPPER IONOSPHERE AND INTERPLANETARY SPACE BY PLASMA WAVE RADIATION *

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ABSTRACT

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It is suggested that measurement of electron concentrations in the upper ionosphere and interplanetary space by determining the resistance of antenna plasma-wave radiation presents a number of advantages over methods in which a major role is played by the Debye shielding and disturbances caused by body motions. Determination of the dependence of radiation impedance on frequency makes it possible to evaluate plasma frequency and thereby plasma electron concentration, since the errors attributable to the presence of a constant magnetic field are small and can be accounted for when the magnetic field intnesity is known. The expression for radiation impedance of an elementary dipole is derived for the case of low anisotropy, when a relatively narrow frequency range near the plasma frequency, the plasma wave's refraction index is $\gg 1$, On the basis of this expression the elementary dipole radiation impedance for the upper

* O vozmozhnosti izmereniy elektronnoy kontsentratsii v verkhney ionosfere i mezhplanetnom prostranstve po izlucheniyu plazmennykh voln.

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for the upper part of the F-layer ($n = 3.5 \cdot 10^5$ electrons/cm^3, $T = 10^3$ °K) was calculated to be of the order of $5 \cdot 10^4$ ohm with a dipole length of 5 5 cm. A similar calculation for interplanetary space gas ($n = 10^2$ electr/cm^3 $T = 10^4$ °K) gives the same resistance value for a dipole length of 10^3 cm.

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It is well known that currently there hardly exist somewhat satisfactory methods for electron concentration measurements in the upper ionosphere and in interplanetary space.

The idea was put forth by V. L. Ginzburg, whereby it would be possible to measure the electron concentration of interplanetary gas by way of measuring the resistance of antenna radiation in plasma waves. As is well known, in case of weak anisotropy the plasma waves' refractive index is $n_3 \gg 1$ in a rather narrow frequency range near the plasma frequency. That is why the dipole radiation resistance at these frequencies must have a sharp maximum. Besides, the resistance of antenna radiation is determined at a weak absorption by a sufficiently large spatial region, the dimensions of which are significantly greater than those of Debye shielding. The consequence is that the given method has a series of advantages in comparison with the other methods of local electron concentration measurements, in which the Debye shielding of the body placed in the plasma and the perturbations linked with body motion acquire a significant value.

As to measurements of the resistance of transverse waves' radiation this method is inconvenient from the practical standpoint because of the smallness of the resistance of elementary dipole radiation in transverse waves (see below).

The problem of plasma-wave dipole radiation was solved in the isotropic case by Andronov and Gorodinskiy [1]. A more general problem of electron radiation in an anisotropic medium is examined by Eydman [2]. The results obtained by the latter may be utilized for the determination of elementary dipole radiation impedance in the anisotropic case*. The energy emitted by a charge q into a plasma wave is [2]:

$$W=\frac{q^2 r_0^2 \omega^2 |\omega^2-\omega_H^2|}{4\beta_T^2 c^3 V}\int \frac{n_3 \sin^2\vartheta \, d(\cos\vartheta)}{|R|}, \tag{1}$$

where $n_3=(F/RV\beta_T^2)^{1/2}$ is the refractive index of the plasma wave,

$$F=1-u-V+uV\cos^2\vartheta;$$
$$R=3\sin^4\vartheta/(1-4u)+[1+(5-u)/(1-u)^2]\sin^2\vartheta\cos^2\vartheta+3(1-u)\cos^4\vartheta;$$
$$V=\omega_0^2/\omega^2; \qquad u=\omega_H^2/\omega^2,$$

r_0 is the radius of the charge rotation in the magnetic field, ω, ω_0, ω_H respectively are the operating, the plasma and the gyro-frequencies, ϑ is the angle between the direction of the wave vector K and the direction of the lines of force of the magnetic field, $\beta_T=v_T/c$ is the ratio of the thermal velocity of plasma electrons to the speed of light in the vacuum. The expression for the emitted energy in reference [2] was obtained under the following assumptions:

* In the following we shall always have in mind "dipole plasma-wave radiation impedance" when speaking of "dipole radiation impedance"

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$$\beta_T^2 \ll 1; \quad (v_T K \sin\vartheta/\omega_H)^2 \ll 1; \quad (\beta_T n_3 \cos\vartheta)^2 \ll 1;$$
$$(1-\omega_H^2/\omega^2)^3 \gg \beta_T^2; \quad (1-4\omega_H^2/\omega^2) \gg \beta_T^2; \quad F \gg \beta_T .$$

For an elementary dipole of length r_o and a dipole moment qr_o the radiation resistance is

$$R_\Sigma = \frac{W}{J^2} = \frac{r_0^2|\omega^2-\omega_H^2|}{8\beta_T^2 c^3 V} \int_{\cos\vartheta_1}^{\cos\vartheta_2} \frac{n_3 \sin^2\vartheta}{|R|} d(\cos\vartheta) . \tag{2}$$

The limits of integration may be found in the expression (2) from the following considerations. The propagation of plasma waves is possible under the condition

$$F > 0 ; \tag{3}$$
$$F < 0{,}02 R V^2 . \tag{3a}$$

The inequality $F > 0$ is obvious. The condition (3a) is linked with the presence of Landau attenuation. Assuming indeed a minimum plasma wave length $\lambda_{\text{кр}} = 63D$ [3], where D is the Debye radius*, we have

$$n_{3\text{кр}}^2 = \lambda_0^2/\lambda_{\text{кр}}^2 \quad (\lambda_0 = 2\pi c/\omega).$$

Utilizing the inequality $n_3^2 = F/RV\beta_T^2 < n_{3\text{кр}}^2$, we obtain the condition (3a)

In the problem concerned with the measurement of electron concentration in the ionosphrre and interplanetary the utmost interest resides in the case of weak anisotropy $(u/V \ll 1,\ V < 1)$. According to the ionosphere model brought out in [4], this case is realized for the 300 to 1000 km altitude range and at distances greater than 2.5 — 3 Earth radii. At the same time (2) may be significantly simplified.

Under the condition $u/V \ll 1$ and $V < 1$ we obtain:

$$R_\Sigma = \frac{r_0^2 \omega^2}{24\sqrt{3}\, v_T^3\, V^{3/2}} I; \tag{4}$$

$$I = \sqrt{u} \int_{\cos\vartheta_1}^{\cos\vartheta_2} \sqrt{V'/u - \sin^2\vartheta}\, \sin^2\vartheta \, d(\cos\vartheta), \tag{5}$$

where $V' = 1 - V \simeq 2\Delta\omega/\omega_0$, $\Delta\omega = \omega - \omega_0$. The integration limits in the expression (5) are easily determinable from the conditions (3) and (3a).

Plotted are in Fig. 1 the results of computation of the dependence of I on V' for varias values of u. It may be seen from the diagram that the quantity I varies significantly faster at small detunings than the multiplier ahead of I in the expression (4) for the radiation resistance. That is why we may consider that the variation of radiation resistance with frequency is characterized by the dependence I (V').

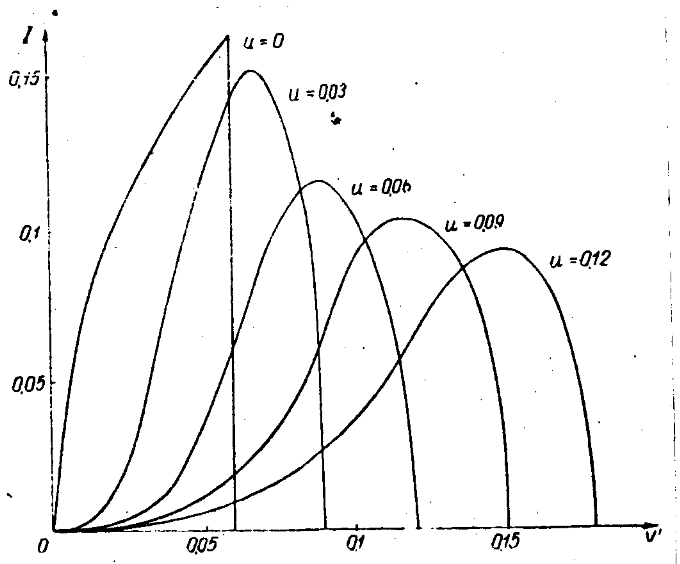

Fig. 1

It must be noted that the maximum value I and the character of the curve I (V') — its width and the accretion speed near the maximum — are little dependent on the quantity u. The behavior of the curves in the dropping portion is conditioned by Landau attenuation and is dependent on the choise of λ_{kp}. The value of the maximum of I, and consequently also that of the radiation resistance for various u, correspond to different V'_0, and at the same time $V'_0 \simeq u + 0.03$. Therefore the maximum value of radiation resistance is obtained at frequencies near the plasma frequency.

Measurements of the dependence on frequency of radiation resistance provide the possibility of determining the value of plasma frequency, and by the same token the plasma electron concentration. The errors stemming from the presence of a constant magnetic field are small and may be easily accounted for, provided the value of the magnetic field is known. Besides, measurements of the absolute value of radiation resistance in the ascending branch of the curve $R_\Sigma (V')$ allow to determine the thermal velocity of electrons v_T (see (4)), and consequently the temperature of the electron gas.

The calculation of the resistance of elementary dipole radiation for the upper part of the F-layer ($N = 3.5 \cdot 10^5$ electron $\cdot$ cm^{-3}, $T = 10^3$ K) gives a magnitude of the order of $5 \cdot 10^4$ ohm for a dipole length of 5 cm. A similar calculation for interplanetary gas ($n = 10^2$ electron$\cdot cm^{-3}$, $T = 10^4$ ° K) gives the R_Σ the same value for a dipole length $r_0 = 10^3$ cm.

For comparison let us point out that the radiation impedance of such dipoles for transverse waves in the same frequencies constitutes thousandths of one ohm.

In reality, a sharp transition from weak transverse wave radiation to an intense plasma-wave radiation will be observed at variation of radiation frequency of gas' electron density. At the side of low frequencies the plasma wave radiation is limited by the sharp drop of the refractive index n_3, and at the side of high frequencies — by a strong effect of the Laudau attenuation mechanism. The plasma-wave radiation impedance reaches an enormous value in a comparatively narrow frequency band ($\Delta\omega/\omega \simeq 0{,}03$). For the above-presented cases it constitutes $\sim 10^5$ ohms. It is quite natural that such radiation impedances may be easily measured with the help of simplest radiotechnical means.

A possible effect upon plasma wave Debye shielding and plasma disturbances, linked with body motion and the ponderomotive effect of antenna field itself*, will apparently manifest itself in the form of Landau attenuation effect increase in the immediate vicinity of the antenna, because of lower electron concentration. This may not only lead to a diminution of the active part of radiation impedance R_Σ, but also to the appearance of reactance. However, inasmuch as the magnitude of the perturbed region does not significantly exceed the Debye radius dimensions, the variation effect of radiation impedance would hardly be great for plasma waves, whose length is comparable with that region's dimensions. The presentation of quantitative estimates of this effect in the current paper appears to be impossible. However, even in the case whereby radiation impedance should

* see next page.

decrease by one — two orders on account of various such factors, this would not apparently lower the precision of electron concentration measurements, for the remaining part of radiation impedance will still constitute a significant quantity.

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******** THE END ********

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REFERENCES FOLLOW

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* From the preceding page.

The ponderomotive effect of antenna high-frequency field may lead to substantial plasma perturbations near the antenna.

REFERENCES

1. A. A. ANDRONOV, G. V. GORODINSKIY. Izv.VUZ. "Radiofizika",5, 234, 1962.

2. V. Ya. EYDMAN, ZhETF, 41, 1971, 1961.

3. V. L. GINZBURG. Rasprostraneniye elektromagnitnykh voln v plazme (Electromagnetic Wave Propagation in the Plasma). FIZMATGIZ., M., 1960.

4. Ya. L. AL'PERT. Rasprostraneniye radiovoln v ionosfere. (Radiowave Propagation in the Ionosphere). Izd.A.N.SSSR, M, 1960.

5. G. G. GETMANTSEV, N. G. DENISOV. Geomagnetizm i Aeronomiya (in print).